Modern Biology
Computerized Laboratories

Photosynthesis

Apple® Version

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MODERN BIOLOGY
Computerized Laboratories

PHOTOSYNTHESIS

Teacher's Manual

Holt, Rinehart and Winston

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MODERN BIOLOGY
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Photosynthesis
Teacher's Manual

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Section 1

Introduction

The *MODERN BIOLOGY* Computerized Laboratories series combines simulations of biological experiments with selected tutorials that enrich and expand students' understanding of concepts learned in the *Modern Biology* textbook. The *Photosynthesis* program presents a group of six experiments designed to foster progressively deeper insight into the process of photosynthesis. These simulations replicate as closely as possible the logic of actual laboratory experiments. They lead students to apply the scientific method: to observe, question, experiment, record, analyze, and interpret results. In addition, highly graphic, interactive tutorials support the simulations. The tutorials provide a thorough content review.

Your *Modern Biology: Photosynthesis* package includes:

- One double-sided program disk
- One Teacher's Manual with 12 reproducible Laboratory Worksheet masters

To use this program in your classroom you will need:

- An Apple IIe, IIc or IIGS computer, 128K required
- A video monitor or TV (color is preferable but not required)

This Teacher's Manual explains how to use the *Modern Biology* software, describes the contents of the *Photosynthesis* disk, and provides strategies for using the software in the classroom.

Section 2

Making a Backup

It is always to your benefit to make a copy of your important disks in case of accidental loss or damage. **Make copies of the *Modern Biology* Disk for every day use and store the original disk for safekeeping.** Use either of the following copy methods.

> Note
>
> Before copying your software, place a write-protect tab (the small adhesive stickers are included with the purchase of blank diskettes) over the squared cutout on the original *Modern Biology* Disk.

Copying Disks with a DOS 3.3 System Master

You need two single-sided blank disks to copy the original disk. Label one disk Side 1 and the other disk Side 2.

1. Turn off the computer. Insert the DOS 3.3 System Master disk in Drive 1. Turn on the computer.
2. Press the CAPS LOCK key in the down position.
3. When the red "In Use" light on the disk goes out and you see a blinking cursor on the screen, type RUN COPYA. Press RETURN.
4. When the red "In Use" light on the disk goes out, remove the DOS 3.3 System Master disk.
5. Insert the original *Modern Biology* Disk in Drive 1 (with Side 1 facing up) and the blank disk in Drive 2 (with Side 1 facing up). Be sure there is no write-protect tab on the blank disk. Press RETURN.

6. You are then prompted for the original slot and drive numbers. Enter **6** as the slot number and **1** as the drive number. Press RETURN after you enter both numbers. Next you are prompted for the duplicate slot and drive numbers. Enter **6** as the slot number and **2** as the drive number. Press RETURN after you enter both numbers.
7. The copy process then begins. When it is complete, the question **Do you wish to make another copy?** appears on the screen. Enter **Y** in response to the question. Press RETURN. Remove both disks.
8. Insert the original *Modern Biology* Disk (with Side 2 facing up) in Drive 1 and the target disk (with Side 2 facing up) in Drive 2.
9. Follow step 6. When you are finished copying disks, enter **N** in response to **Do you wish to make another copy?** Press RETURN.

Copying Disks with a ProDOS Master

You need two single-sided blank disks to copy the original disk. Label one disk Side 1 and the other disk Side 2.

1. Turn off the computer. Insert the ProDOS Master disk in Drive 1. Turn on the computer. The ProDOS User's Disk Main Menu appears.
2. Press **F** to select the **ProDOS FILER (UTILITIES)** option. The Filer Menu then appears.
3. Press **V** to select the **VOLUME COMMANDS** option. The Volume Commands Menu then appears.
4. Press **C** to select the **COPY A VOLUME** option. The Copy A Volume Menu then appears.
5. Remove the ProDOS Master disk.
6. You are then prompted for the slot and drive numbers. Enter **6** as the source slot number and **1** as the source drive number. The cursor automatically moves to the next line on the screen. Enter **6** as the target slot number and **2** as the target drive number. The message, **INSERT DISKS AND PRESS <RET>,** then appears at the bottom of the screen.
7. Insert the original *Modern Biology* Disk in Drive 1 (with Side 1 facing up) and the blank target disk in Drive 2 (with Side 1 facing up). Be sure there is no write-protect tab on the blank disk. Press RETURN.
8. Enter the name you want to give the target volume (no more than 15 characters) then press RETURN.
   If the target disk is not blank, you are asked to confirm that you want to destroy the information that is saved on the disk. Enter **Y** to continue copying.
   When the message **COPY COMPLETE** appears near the bottom of the screen, press RETURN and remove both disks.
9. Repeat step 6.
10. Insert the original disk (with Side 2 facing up) in Drive 1 and the target disk (with Side 2 facing up) in Drive 2.
11. Repeat step 8. When you are finished, turn off the computer.

Section 3

Loading Modern Biology: Photosynthesis

To load your software:

1. Hold the disk by the label and insert Side 1 into the disk drive. Close the disk drive door. If you have two disk drives, use Drive 1.
2. Turn on the computer and the monitor or television set.
3. You will hear whirring noises as the program loads. After the title screen appears, follow the instructions on the screen.

Section 4

Teaching with Modern Biology: Photosynthesis

Modern Biology: Photosynthesis gives you a powerful set of tools with which to augment your teaching of *Modern Biology*. The software has two primary goals:

- To reinforce students' knowledge of both photosynthesis and the scientific method through laboratory simulations of experiments that are difficult or impossible to perform in the high school biology lab.
- To use the graphics, interaction, and animation capabilities of the computer to present concepts that are difficult to teach with conventional methods.

The four units of the program are: Introduction to Photosynthesis, The Light Reaction, The Dark Reaction—C3 Plants, and The Dark Reaction—C4 and CAM Plants. They can be used sequentially or independently of one another. Each lab and theory module is carefully structured to require little or no teacher support, and further, to take no more than 20 to 30 minutes to complete.

To benefit most from the *Photosynthesis* software, your students should already be familiar with the following concepts:

- Scientific method
- Characteristics of living things
- The nature of energy
- Atoms and molecular bonds
- Cell structure
- Enzymes and their role in cells

Modern Biology: Photosynthesis covers the following content:

1. Introduction to Photosynthesis

A. Lab: Rate of Photosynthesis—Levels 1 and 2
Students investigate the effects of light alone or of temperature and light together on the rate of photosynthesis in the freshwater plant *Elodea* sp.

B. Theory: Review of Photosynthesis
The theory module reviews the concept of photosynthesis, then uses a zoom sequence to introduce the plant cell, site of photosynthesis. The steps in the zoom sequence proceed from the leaf surface through a submicroscopic view of the chloroplast structure. Molecular models of chlorophyll a and b are also covered.

2. The Light Reaction

A. Lab: Light Absorption—Levels 1 and 2
Students investigate the absorbance characteristics of a crude plant extract or of individual pigments (in the Level 2 experiment) by exposing the extracts to light of differing wavelengths. Students are led to conclude that light in the red and blue portions of the spectrum trigger photosynthesis, and further, that chlorophyll a and b are most responsible for the absorbance pattern seen in the crude extract.

B. Theory: Review of the Light Reaction
The theory module defines the light reaction, then provides a detailed, animated presentation of the process from photolysis through the formation of NADPH, O_2, and ATP.

3. The Dark Reaction—C3 Plants

A. Lab: Calvin's Experiment
This simulation of Calvin's experiment lets students map the dark reaction cycle in C3 plants by identifying radioactively labeled compounds produced by *Chlorella* sp. in samples taken over time. Students will be encouraged to

repeat the experiment until they have identified the correct sequence of dark reaction products.

B. Theory: Review of the Dark Reaction—C3 Plants
This animated tutorial shows the incorporation of carbon dioxide, the role of light reaction products, and the end products of the dark reaction. The final part of the tutorial recaps the overall reaction of photosynthesis.

4. The Dark Reaction—C4 and CAM Plants

A. Lab: Calvin's Experiment Applied to C4 Plants
This simulation repeats Calvin's Experiment, but with a C4 instead of a C3 plant.

B. Theory: Review of the Dark Reaction—C4 and CAM Plants
The tutorial introduces C4 and CAM plants, then uses an animated representation of the dark reaction cycle as it occurs in these plants to demonstrate the adaptations they have made to their environments.

Section 5

Using Modern Biology: Photosynthesis

Special Keys

Modern Biology software uses clear, on-screen prompts throughout to guide the user. There is, however, one special key that does not appear on screen: ESC.

The ESC key will take the user back to the previous menu. The user who presses ESC when in the middle of a tutorial or lab will return to the submenu. Pressing ESC from a submenu will return the user to the main menu. If the user has come to a tutorial from a lab rather than from a menu (this feature is described in greater detail later in this manual, under laboratory help options), ESC will return the user to the lab.

The Main Menu

The Main Menu for *Modern Biology: Photosynthesis* offers the following choices:

1. Introduction to Photosynthesis
2. The Light Reaction
3. The Dark Reaction—C3 Plants
4. The Dark Reaction—C4 and CAM Plants

Use the ↑ (up) and ↓ (down) arrow keys to highlight the unit you want, then press RETURN to select. You will use this basic menu selection technique throughout the program.

Once you have selected a unit to study, you will have two choices: to go directly to the laboratory simulation or to review the tutorial. The following is a description of interactions necessary to use these modules.

Laboratory Simulations

Each laboratory simulation is divided into three major sections: Protocol, Laboratory, and Conclusions. In addition, some of the labs offer experiments at two levels, each with its own protocol, laboratory, and conclusions.

Protocol: The protocol screens introduce the experiment, let you select a hypothesis to test, and provide a review of the procedure for running the experiment. Clear, on-screen prompts guide the student through this part of the

simulation. No special instructions are necessary.

Laboratory: The lab screens are divided into four parts. A command menu that runs across the top of the screen lets you set up and run an experiment, see experimental results in graphic rather than tabular form, exit from the experiment, or receive help. Use the ← (left) and → (right) arrow keys to choose an option and RETURN to select. A text area at the bottom part of the screen provides instructions, prompts, and feedback. The central part of the screen contains the lab set-up on the left and a note pad on the right. The note pad contains a clock, temperature and light gauges as necessary, plus a space for recording results.

If you select ? (Help) from the command menu, you have three options:

- Commands: tells you how to use the command menu.
- Procedure: reviews the procedure for running the experiment.
- Theory: takes you to the content tutorial. By pressing ESC, you can move from the lab to the tutorial and back again at any time, except while an experiment is actually running or while tutorial questions are being asked. You will always return to where you left off in the lab. Use the ↑ (up) and ↓ (down) arrow keys to cycle through these choices and press RETURN to lock in your selections.

Conclusions: Each lab concludes with a series of questions to encourage students to interpret their experimental results and determine whether or not their hypothesis is correct. The program provides immediate feedback to both correct and incorrect responses.

Tutorials

The theory modules use two central approaches in presenting material—one for presenting structures such as the leaf, the other for presenting processes such as the Calvin Cycle. Structures are presented through a student-controlled "zoom" sequence that moves through increasingly detailed studies of the organism. Processes are presented through student-controlled animation sequences. As the student presses a key, the computer simulates the next step of the process under study. In addition to the zoom and animation routines, the theory modules incorporate interactive questions with immediate feedback to help students integrate the material they are learning. Except where specifically instructed, students use two basic keys to move through the tutorials:

→ moves forward a screen
← moves back one or more screens

Some questions in the tutorials require students to enter a number. In all of these cases, the computer will accept numbers only within a certain range. If the student tries to enter a number out of range (or a character other than a number), the computer will beep. If this happens, press the back arrow key to erase the entry and try again. Most often, the range of acceptable numbers reflects the range of legitimate answers to the question asked. The highest number the computer will ever accept is 10000.

Uses in the Classroom

Modern Biology: Photosynthesis is carefully designed to provide maximum flexibility for classroom use. Both the labs and tutorials are appropriate for:

- **Individual Student Work**

The tutorials provide an excellent introduction to or review of concepts underlying the labs. Because students can move both forward and backward through the tutorials (and back and forth from a lab to a tutorial), they can master the material at their own pace. The labs also provide excellent opportunities for self-paced, individualized learning.

- **Cooperative Learning**

The labs can stimulate interesting group work and discussion. Three students

working together, for example, could each select a different hypothesis to test, record experimental results, then discuss these results relative to the different hypotheses before answering the laboratory's concluding questions.

- **Whole Class Presentations**

You can use both the labs and the tutorials for classroom demonstrations. The modular presentation of the tutorial material makes it easy to find specific sections (an animated review of the light reaction, for example) that can reinforce your classroom teaching.

How to Use the Laboratory Worksheets

Reproduce enough copies of the Laboratory Worksheets to give one to each student who will use the *Modern Biology* simulations. Hand out the appropriate worksheets before students begin the lab. Have students fill in Part I of the worksheet as they review the Protocol section of the lab. As students run the lab, they should record their results in Part II of the worksheet. If you anticipate that students will run the experiment more than once, provide additional copies of the worksheets so that they can record data for each experiment.

Encourage students to fill in Part III of the worksheet before they answer the concluding questions in the laboratory simulation. In this way, they can double-check their own reasoning against the simulation's concluding questions.

You can use Part IV of the worksheets as enrichments or as quizzes to conclude your teaching unit on the process of photosynthesis.

Section 6

Laboratory Enrichments with Worksheets

Introduction to Photosynthesis

Theory: Review of Photosynthesis

Objectives:

- To illustrate the structure of a leaf cell.
- To describe chloroplast structure.
- To describe the importance of ATP and glucose.
- To write the formula that summarizes photosynthesis.
- To subdivide the overall process into the light reactions and the dark reactions.
- To describe some of the features of the chlorophyll and ATP molecules.

Teaching ideas:

This tutorial provides a complete review of photosynthesis. You can use it either as students' initial exposure to the process or to review the process after class activities. Some recommended activities: Make wet mounds of *Elodea* sp. leaves for microscopic examination; if you have electron micrographs, have students examine the internal structure of the chloroplast as well; have students build models of a chloroplast with the compartmentalization intact.

Enrichments:

Have students compare chloroplast structure and function with mitochondrial structure and function. Lead advanced students to examine evidence for the Endosymbiotic Theory of the origin of these organelles.

References:

T. D. Brock, D. W. Smith, and M. T. Madigan. *Biology of Microorganisms, 4th ed.* Englewood Cliffs, NJ: Prentice-Hall, Inc., 1984, pp. 764-765.

Lab: Rate of Photosynthesis, Level 1

Objectives:

- To understand photosynthesis as a complex process in which oxygen is produced, some of which can be collected and measured.
- To use experimental data to explain the effects of varying light intensities on the rate of photosynthesis in *Elodea* sp.

Teaching ideas:

Before using this simulation, discuss some of the following questions with students:

1. Is photosynthesis measurable?
2. How can it be measured and in what kind of units?
3. What kind of organism should be used in the experiment?
4. How should we organize the data?

After students have considered these issues, encourage them to formulate hypotheses and make predictions.

The variable in this experiment is light intensity. Discuss the meaning of intensity and some ways in which it can be measured, including microEinsteins, the unit plant physiologists and this lab use (see Glossary for a definition of microEinsteins). Challenge students to develop alternative experimental designs for measuring the rate of photosynthesis, e.g., changing the distance between the light source and the plant.

Enrichments:

1. Demonstrate an alternative approach to this experiment in the classroom. Use lightbulbs as the light source and a pH indicator (such as bromothymol blue) to measure the plant's use of the CO_2.
2. Set up an aquarium to introduce the role of the products of photosynthesis in the ecosystem and the importance of the process in nature.
3. Discuss the following, related principles to strengthen and clarify the students' appreciation of biological processes:
   - The meaning of energy and its transformations.
   - Diffusion of materials through water.
   - The effect of temperature on gas solubility and diffusion.

References:

P. Abramoff and R. G. Thomson. *Laboratory Outlines in Biology—IV.* San Francisco,: W. H. Freeman and Company, 1986, pp. 139-142.

J. H. Otto, A. Towle, and W. David Otto. *Biology Investigations.* New York: Holt, Rinehart and Winston, Publishers, 1985, pp. 35-36.

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Rate of Photosynthesis—Level 1

NOTE: A microEinstein (μE) is a unit of light intensity equal to 6.023×10^{23} photons. Deep shade has a light intensity of 150 μE; sunlight is 1800 μE.

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

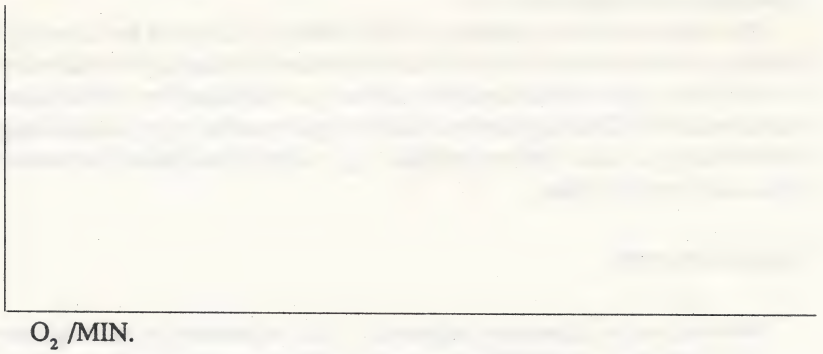
What do you predict will happen? _____

_____

II. Record your data in the table and graph below.

A. Table B. Graph

μE	O_2 /MIN.



III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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Lab: Rate of Photosynthesis—Level 1

IV. Instructions: Answer the following questions on a separate sheet.

1. Why is captured oxygen a reasonable measure of the rate of photosynthesis?

2. Is all of the oxygen produced being captured? If not, where is it going?

3. What is the source of carbon dioxide in this experiment?

4. Where does the carbon dioxide come from in a natural environment? Where does the oxygen go?

5. What organisms could be used in place of *Elodea* sp. in this experiment?

6. Why is the temperature kept constant in this experiment?

7. Does your graph compare favorably with the ideal curve? What might be the reason for differences?

8. Describe the relationship between light intensity and the rate of photosynthesis.

9. Why must you test a wide range of light intensities in order to see the full relationship between the rate of photosynthesis and light intensity?

10. Why do you think that the rate of photosynthesis levels off at high intensities?

11. What other variables could you test to gain more information about photosynthesis?

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Lab: Rate of Photosynthesis—Level 2

Objectives:

- To demonstrate the relationship between temperature, light intensity, and the rate of photosynthesis in *Elodea* sp.
- To represent this relationship graphically.

Teaching ideas:

Students will understand this simulation better if they are familiar with the concept of temperature as it relates to the kinetic energy of molecules and the probability of collision. Have students recall the effects of heat on solids, liquids, and gases to reinforce the subtle change that takes place on a molecular level as temperature is altered.

Enrichments:

This experiment is based on those performed by Blackwell, who first gathered evidence demonstrating that photosynthesis consists of two processes. The first process, at lower light intensities, is affected by light intensity but not temperature. This is the light reaction. The second process, the dark reaction, is affected by temperature (above saturating intensity) up to a maximum rate. Lead students to draw these conclusions from the experiment, or at least to understand how the evidence reveals the existence of two processes.

References:

L. G. Johnson, *Biology*. Dubuque, IA: William C. Brown Company, Publisher, 1983, pp. 148-151.

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Rate of Photosynthesis—Level 2

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

What do you predict will happen? _____

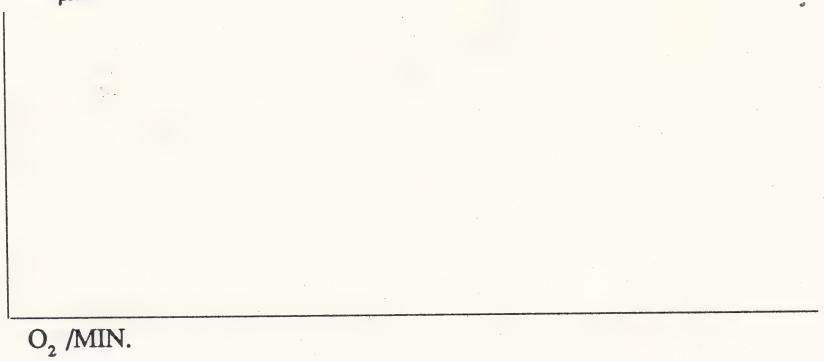
_____

II. Record your data in the table and graph below.

A. Table

µE	O_2 /MIN.

B. Graph



III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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IV. Instructions: Answer the following questions on a separate sheet.

1. What is temperature?

2. How does temperature generally affect the rate of chemical reactions?

3. Do plants such as *Elodea* sp. maintain a constant internal body temperature?

4. What molecules control chemical reactions inside living plant cells?

5. Are these "controlling molecules" sensitive to temperature?

6. What is the basic relationship between temperature and the rate of photosynthesis?

7. What could explain the fact that increases in temperature stop affecting rate of photosynthesis after a point?

8. Are some plants better adapted to higher temperatures than others?

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The Light Reaction

Theory: Review of the Light Reaction

Objectives:

- To list the molecules involved in the light reactions and the products formed.
- To explain the significance of the products formed for supplying the dark reactions.
- To describe the site of the light reaction and the relationship between photosystems I and II.
- To explain the importance of the electron transport system in the light reaction.
- To describe how the build up of hydrogen ions in the thylakoid lumen contributes to ATP formation.

Teaching ideas:

Use the program's animated presentation of the light reaction as a visual aid when you first teach this material in class.

Have students make models of a chloroplast, including representations of the photosystems and the electron transport chain.

Have students compare the function of the electron transport chain in cellular respiration and photosynthesis.

Enrichments:

Students might enjoy studying one of the following related topics:

- Photosystems and their origin.
- Differences in photosynthesis in bacteriea, algae, and plants.
- The evolution of photosynthesis and the change in our atmosphere from a reducing to an oxidizing one.

References:

R. Wallace, J. King, and G. Sanders. *Biosphere: The Realm of Life*. Glenview, IL: Scott, Foresman and Company, 1984, pp. 95-108.

L. Margulis. *Early Life*. Boston: Jones & Bartlett Publishers, Inc., 1984, pp. 43-61.

Lab: Light Absorption—Level 1

Objectives:

- To list the wavelengths and colors of light absorbed by an extract of leaf pigments.
- To explain the color of the extract based on absorption data.
- To suggest which wavelengths trigger photosynthesis based on absorption data.

Teaching ideas:

Prior to using this laboratory, have your class use prisms or a spectroscope, if available, to split white light into a spectrum.

Students often confuse the terms *pigments* and *wavelengths*. Give your class clear definitions (see Glossary) of both terms and provide a chance for them to practice using them.

Enrichments:

If you have a spectroscope, position a tube of leaf extract between it and a light source so that students can actually see which colors are absorbed and transmitted through the leaf extract.

References:

P. Abramoff and R. G. Thomson. *Laboratory Outlines in Biology—IV.* San Francisco: W. H. Freeman and Company, 1986, pp. 146-148.

F. H. Witham, D. F. Blaydes, and R. M. Devlin. *Exercises in Plant Physiology, 2d ed.* Boston; Prindle, Weber & Schmidt, 1985, pp. 128-131.

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Light Absorption—Level 1

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

What do you predict will happen? _____

_____

II. Record your data in the table and graph below.

A. Table B. Graph

WAVELENGTH	ABSORBANCE

ABSORBANCE

WAVELENGTH

III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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IV. Instructions: Answer the following questions on a separate sheet.

1. What is a pigment?

2. Explain why the words *color* and *wavelength* can be used interchangeably.

3. If you shined white light through a prism, how would it appear?

4. List the colors of the light spectrum by wavelength (in nm).

5. Does a leaf appear green because it absorbs or reflects green light?

6. Based on the results of this experiment, which colors are absorbed by the leaf extract and which colors are not?

7. If you could shine white light through a prism and then pass that light through your leaf extract, what colors would you see?

8. Do all pigments in plants play a role in photosynthesis?

9. How might plants use light other than for photosynthesis?

10. Light energy changes both water and chlorophyll in the chloroplast. How does light energy change water? How does it change chlorophyll?

11. Is carbon dioxide used in the light reaction?

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Lab: Light Absorption—Level 2

Objectives:

- To list four pigments present in the crude extract.
- To list the wavelengths of light each pigment absorbs and those each one does not absorb.
- To relate these data to the absorption pattern of the crude extract as seen in the Level 1 experiment.

Teaching ideas:

Chromatography is a process that in this experiment is used to separate pigments from a plant leaf extract. This process usually involves volatile and dangerous chemicals and therefore is not usually done in a high school biology class. However, you can help students appreciate the process through which leaf pigments are separated by setting up a chromatography experiment using ink mixtures or food coloring.

Enrichments:

You can extend your students' understanding of light absorption by challenging them to think about algae at various depths in the ocean. What type of light penetrates the ocean? Does this have an impact on the types of pigments found in algae at different depths?

References:

P. Abramoff and R. G. Thomson. *Laboratory Outlines in Biology—IV*. San Francisco: W. H. Freeman and Company, 1986, pp. 146-148.

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Light Absorption—Level 2

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

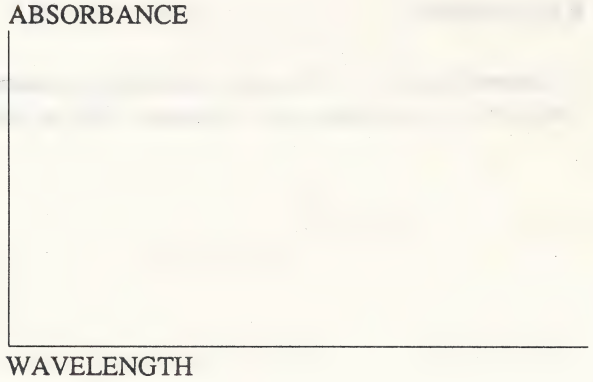
What do you predict will happen? _____

_____

II. Record you data in the table and graph below.

A. Table B. Graph

WAVELENGTH	ABSORBANCE



III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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Lab: Light Absorption—Level 2

IV. Instructions: Answer the following questions on a separate sheet.

1. Is chlorophyll the only pigment in green leaves?

2. Which colors of the spectrum does chlorophyll absorb?

3. Which colors of the spectrum do carotenes absorb?

4. If leaves have orange and yellow pigments, why do they appear green?

5. Give one hypothesis explaining how leaves turn color in the fall.

6. Use the terms *light energy* and *chemical energy* to describe the function of pigments in the light reaction.

7. Which of the pigments that you've studied are accessory pigments? Why are they called accessory?

8. How do the results of this experiment explain the absorption spectrum of the crude extract generated in the Level 1 lab?

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The Dark Reaction—C3 Plants

Theory: Review of the Dark Reaction in C3 Plants

Objectives:

- To show where the dark reaction occurs in the thylakoid.
- To list the products of the light reaction that are used in the dark reaction and to describe their contributions.
- To describe the significance of ribulose diphosphate carboxylase in carbon dioxide fixation.
- To explain why phosphoglyceraldehyde (PGAL) is a critical substance and often considered to be the product of the Calvin cycle.
- To present a chemical formula that represents the reactants and the products of the dark reactions.

Teaching ideas:

Discuss the ways in which plants use dark reaction products to support normal functioning and growth. Help students see the value of these products not only to plants but also to organisms that eat plants. The nutritional value of a plant's components (e.g., cellulose, protein in the form of enzymes, and membrane subunits) is interesting and relevant to students.

Enrichments:

Explore the biochemistry of PGAL conversion into many other molecules. Lead students to discover the central role of carbohydrate metabolism and how carbohydrates are related to proteins and lipids.

References:

L. G. Johnson. *Biology*. Dubuque, IA: William C. Brown Company, Publishers, 1983, pp. 162-168.

Lab: Calvin's Experiment

Objectives:

- To list the molecules that constitute the Calvin cycle.
- To arrange these molecules in the order in which they incorporate radioactive carbon as the Calvin cycle proceeds.

Teaching ideas:

Discuss radioactivity and the use of tracers before beginning this simulation. List and evaluate detection devices as they apply to this experimental design.

Chlorella sp. the organism used in this simulation, can be found in lakes and ponds or purchased from a biological supply house. Have students make wet mounts of *Chlorella* sp. and study them under the microscope.

Enrichments:

If students apply Lugol's iodine to leaves that have been exposed to hot water or hot alcohol, they can detect stored photosynthate in the form of starch. If they use variegated leaves, the starch pattern will parallel the chlorophyll pattern in the leaf.

References:

P. Abramoff and R. G. Thomson. *Laboratory Outlines in Biology—IV*. San Francisco: W. H. Freeman and Company, 1986, pp. 139-142.

J. A. Bassham and M. Calvin. *The Path of Carbon in Photosynthesis*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1957, pp. 34-43. (This is a reference to the original experiment.)

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Calvin's Experiment

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

What do you predict will happen? _____

_____

II. Copy your data on the representative strips. Record the time for which you ran each trial.

KNOWN	1	2	3	4	5
DPG					
PGAL					
PGA					
RUBP					
GLUCOSE					
TIME:	_____	_____	_____	_____	_____

III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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Lab: Calvin's Experiment

IV. Instructions: Answer the following questions on a separate sheet.

1. Why is the dark reaction called the dark reaction?

2. Why are small, single-celled organisms used in this experiment:

3. Why is radioactive carbon dioxide ($^{14}CO_2$) used in this experiment?

4. What might make this experiment difficult to run in a real lab?

5. Sketch one molecule each of carbon dioxide, water, and glucose.

6. How many atoms of carbon does a carbon dioxide molecule have?

7. How many atoms of carbon does a glucose molecule have?

8. How many turns of the Calvin cycle are necessary to create one molecule of glucose?

9. Where does the energy that fuels the Calvin cycle come from?

10. Can we draw the following conclusion from this experiment: "All photosynthetic organisms produce the same products, in the same order, as *Chlorella* sp." Why or why not?

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The Dark Reaction—C4 and CAM Plants

Lab: Calvin's Experiment Applied to C4 Plants

Objectives:

- To list in order the intermediates in which radioactively labeled carbon appears.
- To compare these data with the results of the previous simulation, Calvin's experiment with C3 plants.

Teaching ideas:

Describe the inhibiting effect of photorespiration on the dark reaction in C3 plants and how the reduction in photorespiration gives C4 plants a metabolic advantage. Describe the biochemical and structural differences between C3 and C4 plants and how biochemistry and anatomy relate to one another.

Enrichments:

Conduct studies comparing the growth of C3 and C4 seeds. Measure variables such as light intensity and use of carbon dioxide.

References:

L. G. Johnson. *Biology*. Dubuque, IA: William C. Brown Company, Publishers, 1983, pp. 162-168.

Theory: Review of the Dark Reaction in C4 and CAM Plants

Objectives:

- To describe the two carbon dioxide fixation reactions that occur in C4 and CAM plants.
- To compare and contrast C3 and C4 metabolism.
- To compare and contrast C4 and CAM metabolism.
- To relate the biochemical, anatomical, and physiological differences in C4 and CAM plants.
- To explain why C4 and CAM plants can inhabit areas C3 plants cannot inhabit.

Teaching ideas:

Have students compile lists of food crops and find out whether they are C3 or C4 plants. Mark where these crops grow on a world map and discuss the reasons for this distribution.

Have students study leaf cross sections of C3 and C4 plants microscopically. Have them sketch the mesophyll and bundle sheath cells and then identify where the relevant dark reactions take place in each.

Enrichments:

Have advanced students research the evolution of C4 metabolism from C3 metabolism in certain plant families.

References:

F. B. Salisbury and C. Ross. *Plant Physiology*. Belmont, CA: Wadsworth Publishing Co., 1985, pp. 194-215.

P. H. Raven, R. F. Evert, and S. Eichhorn. *Biology of Plants*. New York: Worth Publishers, Inc., 1987. p. 111.

Name _____ Date _____

LABORATORY WORKSHEET

Lab: Calvin's Experiment Applied to C4 Plants

I. What is the purpose of this experiment? _____

_____

What is your hypothesis? _____

_____

What variable(s) are you changing? _____

_____

What do you predict will happen? _____

_____

II. Copy your data on the representative strips. Record the time for which you ran each trial.

KNOWN	1	2	3	4	5
MALIC ACID					
OAA					
PGAL					
PGA					
RUBP					
GLUCOSE					
TIME:	_____	_____	_____	_____	_____

III. Do your data support your hypothesis? _____

What is your conclusion? _____

_____

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Lab: Calvin's Experiment Applied to C4 and CAM Plants

IV. Instructions: Answer the following questions on a separate sheet.

1. Why do you think that small disks cut from a corn leaf are used in this experiment?

2. Why are the leaf disks dropped in alcohol?

3. If you were to look at corn leaves under a microscope, what anatomical feature would indicate that corn is a C4 plant?

4. What would be the best climate in which to collect other C4 plants for use in experiments?

5. If you used a CAM plant for this experiment, how would your results be different? How would they be similar?

6. Predict what would happen if you ran this experiment at a higher temperature?

7. Write an equation showing the first fixation reaction and how it connects to the Calvin cycle. Indicate the type of cell in which each stage occurs.

8. Suggest variables other than temperature that you could test with this experimental set-up.

9. If you added an herbicide to the reaction flask, what might happen to the time at which dark reaction products appear?

10. Why are experiments that help us understand photosynthesis as it occurs in different plants and algae important?

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Section 7

Glossary

acceptor molecules: a chain of molecules in the thylakoid membrane that accept electrons from light-activated chlorophyll.

accessory pigments: plant cell molecules that contribute to the color of the leaf and that pass some energy on to chlorophyll for use in photosynthesis. Carotene and xanthophyll are examples of accessory pigments.

adenosine diphosphate (ADP): an important molecule involved in energy reactions in cells. When ADP bonds with an additional phosphate, it becomes ATP.

adenosine triphospate (ATP): a molecule that contains the chemical energy cells use for many purposes, e.g., making glucose.

ATP synthetase: an enzyme found in the thylakoid membrane that catalyzes the formation of ATP. The flow of hydrogen ions through the thylakoid membrane triggers the activity of this enzyme.

bundle sheath cells: the site of the Calvin cycle in C4 plants. These cells form a ring around the leaf vein.

C3 plants: plants that produce a three-carbon molecule (PGA) early in photosynthesis. Most plants are C3 plants.

C4 plants: plants that produce a four-carbon molecule (OAA) early in photosynthesis, before the regular Calvin (or C3) cycle begins. This special adaptation enables most C4 plants to live in warmer climates than C3 plants. Corn is an example of a C4 plant.

Calvin cycle: the sequence of reactions that enable plants to convert carbon dioxide into glucose and other organic molecules. The dark reaction.

CAM plants: plants with Crassulacean Acid Metabolism. They store carbon dioxide at night for use in the Calvin cycle during the day. This adaptation lets CAM plants survive in hot, dry climates. Jade plants are examples of CAM plants.

chemiosmosis: a theory that explains how plant cells make ATP during photosynthesis. According to chemiosmotic theory, the flow of hydrogen ions through the thylakoid membrane activates the enzyme ATP synthetase, which catalyzes the formation of ATP.

chloroplast: a complex organelle found in cells capable of photosynthesis. Chloroplasts contain all of the enzymes and pigments used in photosynthesis.

chlorophyll: a green pigment found in the chloroplasts of plant cells. When stimulated by light, chlorophyll starts the process of photosynthesis. Plants have two types of chlorophyll, chlorophyll a and chlorophyll b. They are activated by different wavelengths of light.

dark reaction: the sequence of reactions through which a plant converts carbon dioxide and products of the light reaction into glucose. The dark reaction requires no light. It is also called the Calvin cycle.

diphosphoglycerate (DPG): a molecule formed during the dark reaction. DPG is formed when PGA accepts another phosphate from ATP.

electron transport chain: a series of molecules that pick up and release electrons in a sequence. As the electrons pass through the sequence, they give up energy that is used to transport hydrogen ions. These ions will be used to make ATP. Electron transport systems occur in chloroplasts and in mitochondria.

endoplasmic reticulum: flattened, membranous sacs that extend throughout the cell's cytoplasm. Some have ribosomes on their surface.

energy: the ability to do work or cause change. One form of energy can be transformed into another, e.g., light energy into heat energy. Control of energy is one of the basic properties of life.

epidermis: a layer of specialized cells on the upper and lower surfaces of plant leaves, stems, and roots. These cells protect the plant and retain water. They do not play a role in photosynthesis.

glucose: a complex carbohydrate that is the end product of photosynthesis. Glucose supplies the food energy many living things need.

grana: stacks of thylakoids.

ion: an atom that has lost or gained one more electron and thus has a charge. Ions are common and important in the chemical processes that occur in living cells.

light reaction: the first part of photosynthesis. During the light reaction, light energy is used to make ATP and $NADPH_2$.

lumen: the space between the thylakoid walls. Hydrogen

ions accumulate in the lumen during the light reaction.

malate: a four-carbon acid formed in C4 and CAM plants when a molecule of PEP joins with a molecule of CO_2. Malate stores the CO_2 for use in the Calvin cycle.

mesophyll cells: the plant cells in which all or part of photosynthesis occurs. They contain many chloroplasts.

microEinstein (μE): a unit of light intensity equal to 6.023 x 10^{23} photons. Deep shade has a light intensity of 150 μE; sunlight is 1800μE.

mitochondria: bean-shaped organelles that produce most of the ATP that cells make. *Sing.:* mitochondrion.

NADP (nicotinamide adenine dinucleotide phosphate): a hydrogen ion acceptor that is converted into $NADPH_2$ during the light reaction. It supplies hydrogen ions that are used during the dark reaction.

nucleus: the largest organelle in the cell. It contains the genetic material, DNA, that controls most of the activities of the cell.

oxaloacetic acid (OAA): one of the four-carbon molecules formed in C4 and CAM plants when carbon dioxide is attached to PEP. OAA is converted into malate.

phosphoenylpyruvate (PEP): a three-carbon molecule that fixes with CO_2 at the beginning of the dark reaction in C4 and CAM plants.

phosphoglyceraldehyde (PGAL): a three-carbon molecule produced in the Calvin cycle. Plants use PGAL to produce many other molecules, including glucose.

phosphoglycerate (PGA): a three-carbon molecule produced in the Calvin cycle when the unstable six-carbon atom breaks apart. It is the first identifiable carbon-containing molecule formed during the Calvin cycle.

photosynthesis: the complex process through which plants, algae, and certain bacteria convert light energy into chemical energy stored in organic molecules.

photosystems: an organized arrangement of pigment molecules, including accessory pigments and chlorophyll, located in the membrane walls of thylakoids. Plants have two photosystems—photosystem I and photosystem II—that work with other molecules in carrying out the light reaction.

ribulose bisphosphate (RuBP): a five-carbon sugar molecule that accepts carbon dioxide in the first step of the Calvin cycle. RuBP is constantly regenerated in the Calvin cycle.

ribulose bisphosphate carboxylase: the first enzyme used in the Calvin cycle. It enables RuBP to fix carbon dioxide. Ribulose bisphosphate carboxylase is thought to be the most abundant protein on earth.

stoma: a pore in the epidermis of a leaf that lets gases in and out of the leaf interior. *Pl.:* stomata.

stroma: the jelly-like material that surrounds the thylakoids in chloroplasts. The site of the dark reaction. The stroma contains many enzymes, including those involved in the dark reaction.

thylakoid: the membranous, disk-like sac inside a chloroplast that is the site of the light reaction. Each thylakoid contains the photosystems, electron transport systems, and ATP synthetase used in the light reaction.

vacuole: a single-membrane, balloon-like plant cell organelle that stores water and other materials.

Section 8

Answers to Worksheet Questions

Lab: Rate of Photosynthesis—Level 1

1. Rate of photosynthesis is proportional to the amount of oxygen produced.
2. No. The plant uses some for its own respiration; some of the oxygen is dissolved in water.
3. Some carbon dioxide is dissolved in the water surrounding the plant; some is produced by the plant during respiration.
4. All organisms produce carbon dioxide during respiration. Many organisms use oxygen during respiration.
5. Any other water plant, algae, or other photosynthetic protists could replace *Elodea* sp. in this experiment.
6. Temperature is kept constant so that only one variable—changing light intensities—influences the results.
7. If your graph is different, you may have made an error in counting bubbles or reading the manometer. Another possible reason is that all plants are individuals and have slightly different rates of photosynthesis.
8. The rate of photosynthesis increases as light intensity increases until a maximum rate is achieved.
9. If all the values used are too low, you may never see that the rate of photosynthesis levels off. If values are too high, you could miss the direct relationship between increasing light intensity and the increasing rate of photosynthesis.
10. The rate of photosynthesis could level off either because the enzymes involved in the chemical reactions are saturated or because of the decrease in the level of CO_2.
11. You could test amounts of CO_2, temperature, or different wavelengths of light.

Lab: Rate of Photosynthesis—Level 2

1. Temperature is a measure of the amount of heat or kinetic energy contained in a molecule.
2. An increase in temperature causes an increase in the rate of chemical reactions outside of living systems. Inside organisms, however, this may be true only up to a maximum temperature.
3. No. They are the same temperature as their surroundings. Only birds and mammals maintain a constant internal temperature.
4. Enzymes, biological catalysts, control the rate of reactions in living systems.
5. Yes. Enzymes are proteins. Their structure and activity are affected by temperature. High temperatures may permanently change an enzyme.
6. The rate of photosynthesis increases as temperature increases until a maximum rate is achieved.
7. The enzymes that catalyze photosynthesis are altered by high temperature. Their shape is changed so that they can no longer catalyze the reaction.
8. Yes. Some plants, such as tropical plants, can continue to photosynthesize at high temperatures. However, even they have maximum temperatures beyond which the rate of photosynthesis decreases.

Lab: Light Absorption—Level 1

1. A pigment is a complex molecule that absorbs some wavelengths of light and reflects others.
2. White light can be divided into different colors. One of the differences between the colors is their wavelength.
3. You would see all the colors of the spectrum.
4. Violet: 400-455; Blue: 456-495; Green: 496-560; Yellow: 561-575; Orange: 576-595; Red: 596-700.
5. Reflects. Green light reflects off the surface of the leaf and stimulates the eye. Absorbed light is not seen.
6. Blue light of about 440 nm and red light of about 660 nm are absorbed. Other blue and red light, plus green, yellow, and orange are not.
7. You would see all colors except parts of the blue and red light. Bands of black would show instead, indicating that these colors had been absorbed.
8. No.
9. Some pigments serve to attract insects, birds, or bats, who pollinate the plants. These pigments help assure reproduction.
10. Light energy causes water to split into oxygen, electrons, and hydrogen ions. It excites electrons of chlorophyll, which leave the photosystems and initiate the process of photosynthesis.
11. No. CO_2 is not used until the dark reaction, when it combines with other molecules to form the products of photosynthesis, including glucose.

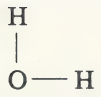
Lab: Light Absorption—Level 2

1. No. Leaves also contain pigments such as carotenes and xanthophylls. These can be separated out of a crude extract.
2. Chlorophyll absorbs in the blue and red regions.
3. Carotenes and other yellow pigments absorb in the blue region only. They reflect all other wavelengths.
4. Chlorophyll molecules so outnumber other pigment molecules that the absorption characteristics of chlorophyll are most obvious.
5. Lower temperatures and decreasing daylight hours lower the amount of chlorophyll, so the other pigments are no longer masked. Also, sugar builds up in the leaves, which causes red pigments to form. The characteristics of these pigments become more visible.
6. Pigments convert light energy into chemical energy in the form of ATP and $NADPH_2$.
7. Carotenes and xanthophylls are accessory pigments. They are called accessory pigments because they pass energy on to chlorophyll. They do not carry out photosynthesis themselves.
8. The absorption spectrum of the mixture is mainly due to the characteristics of the chlorophylls. The absorption characteristics of the yellow pigments are masked.

Lab: Calvin's Experiment

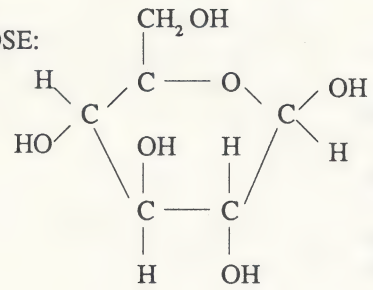
1. The dark reaction is called the dark reaction because it does not require light. It can take place in the light or in the dark and is often referred to as the light independent reaction.
2. Since they are small, they won't shade each other. Photosynthesis can proceed at an optimal rate.
3. $^{14}CO_2$ emits radiation that can be detected on film. Because we can detect the radioactivity, we can trace the carbon atom as it is used by the cell. This is why radioactive compounds such as this are called tracers.
4. Safety is a potential problem when working with radioactive materials. Also, timing this experiment can be very difficult.

5. WATER:



CO_2: O = C = O

GLUCOSE:



6. One.
7. Six.
8. Six.
9. The energy comes from the bond energy in ATP formed during the light reaction.
10. That would be dangerous. We would need to test many different plant and algae samples to support this conclusion. Had scientists accepted this general condition, C4 plants would never have been discovered!

Lab: Calvin's Experiment Applied to C4 Plants

1. Since the disks are small, they won't shade one another. Photosynthesis can proceed at an optimal rate.
2. Methanol kills the cells, stopping photosynthesis. We are able to detect some of the intermediary compounds rather than just the products of photosynthesis.
3. The ring of bundle sheath cells around the veins.
4. Tropical regions have more C4 plants than temperate regions because C4's have adapted to living in areas with higher temperatures and greater light intensity.
5. The timing would be different. CAM plants form malate in the dark; they wait until light to carry out the Calvin cycle. The order of molecules produced, however, is the same.
6. Since C4 plants grow better at higher temperatures than C4 plants, they would photosynthesize more rapidly. The products would appear more quickly or in larger amounts.
7. CO_2 + PEP → OAA → Malate → CO_2 → Calvin Cycle

   Mesophyll Cells — Bundle Sheath Cells

8. You could test the effect of differing light intensities and of different concentrations of CO_2. Both the times at which compounds appear and the amounts formed would change.
9. Some herbicides slow down or stop photosynthesis. They vary in how they affect plant growth and in which plants they affect, however, so some might not change the results of the experiment at all.
10. Photosynthetic organisms provide food and oxygen for nonphotosynthetic organisms. They are the foundation of most food chains. If we understand the process of photosynthesis better, we may be able to increase the yield of food crops or develop new foods.

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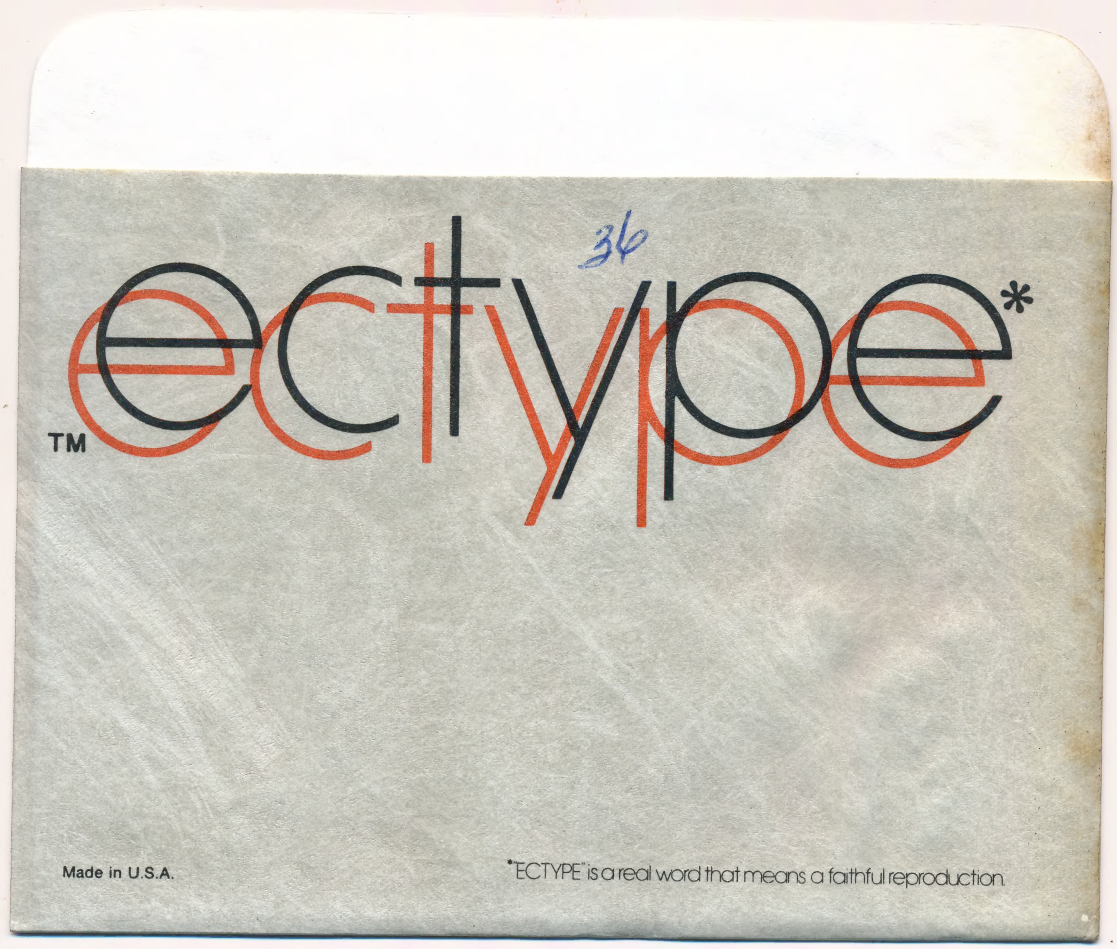
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Photosynthesis

Side 2

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